



Development of Space-Based Laser Systems at Goddard Space Flight Center

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Agenda

- Laser & Electro-Optics Branch at GSFC
- Lidar Applications & Areas of Interest
 - GSFC Solid State Lasers and Fiber Lasers for Space
 - Space-Based Topographic Mapping Lidar Results
 - Laser Interferometer Space Antenna (LISA)
 - Lasers for in-Situ Planetary Lander Instruments
 - New generation lidar instruments
 - Laser Spectroscopy
 - Laser Communications
- General Laser Requirements
- Preparing for the future
- Challenges
- Conclusions
- Acknowledgments



Laser & Electro-Optics Branch at GSFC



Who “we” are:

NASA =>

NASA “science” (i.e. Earth or Space science) =>

NASA Goddard Space Flight Center =>

Science and Engineering (e.g. for lidar altimetry) =>

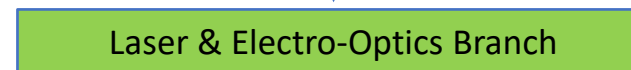
Earth & Planetary Science and (science instrument)
Engineering.

What we do:

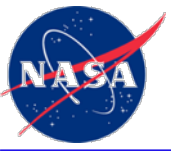
Conceive, propose, design, fabricate, test and deploy one-of-a-kind space (or on a pathway to space) science instruments (e.g., laser altimeters, atmospheric lidars, spectroscopic lidars) AND spacecraft systems (e.g., laser communication, 3D laser vision, etc.)

For whom:

International science community, US taxpayer, other
US Government Agencies.



NASA GSFC Annual Reports can be found at: https://www.nasa.gov/centers/goddard/about/rep_plan.html



Lidar Applications & Areas of Interest



☐ Earth

- Agriculture
- Forestry
- Geology
- Hydrology
- Sea Ice
- Land Cover – Biomass Mapping
- Mapping
- Oceans and Coastal Monitoring

☐ Planetary

- Planetary topography
- Surface, atmosphere and radiant temperatures
- Surface and atmospheric mineral and

chemical compositions

- Gravity, atmospheric pressure and atmospheric density information
- Composition of the planetary surface and/or near-subsurface materials.

☐ Astrophysics

- Gravitational Waves

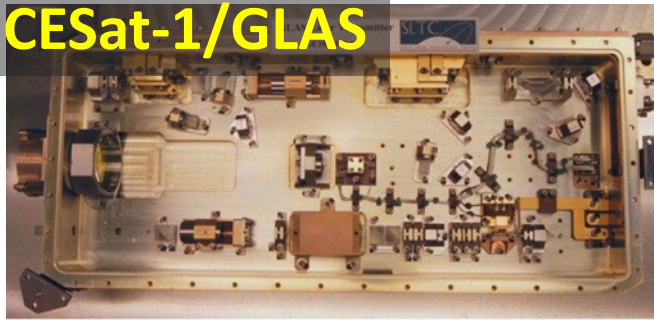
☐ Heliophysics

- Space weather
- Atmospheric Dynamics

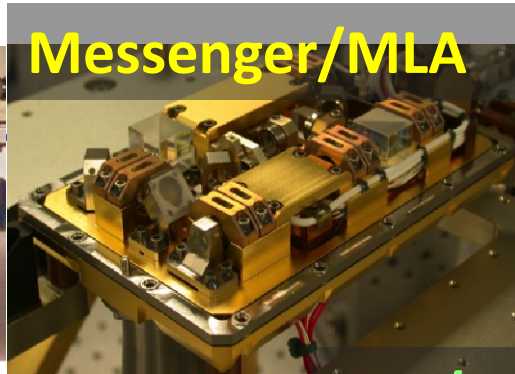
☐ Laser Communications

☐ Satellite Servicing

ICESat-1/GLAS



Messenger/MLA



LRO/LOLA



GED/HOMER



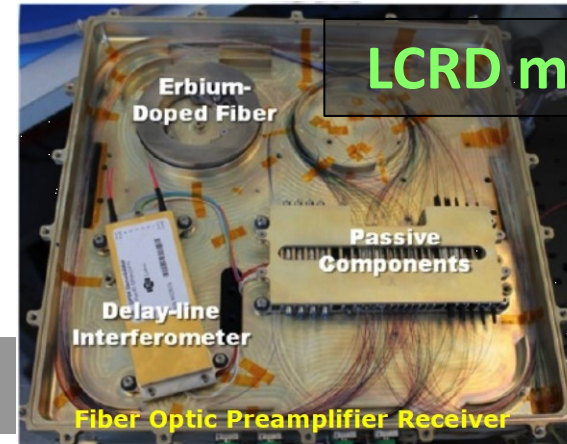
ICESat-2/ATLAS



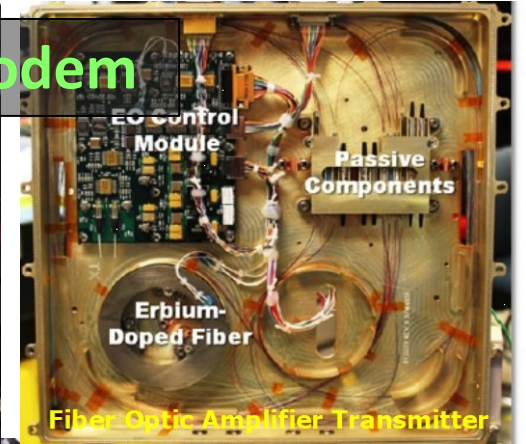
Dragonfly/THANOS



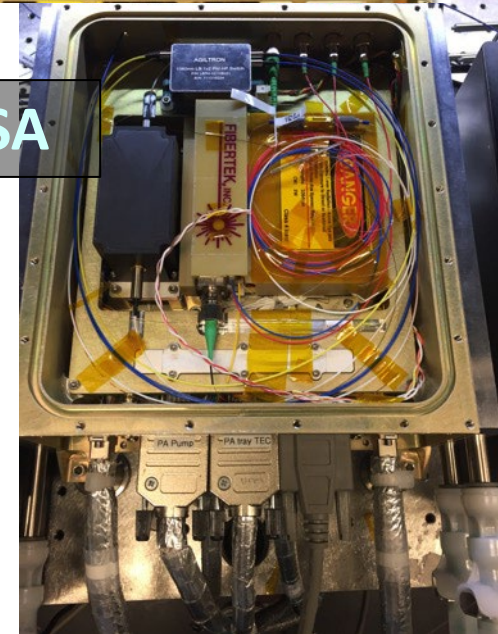
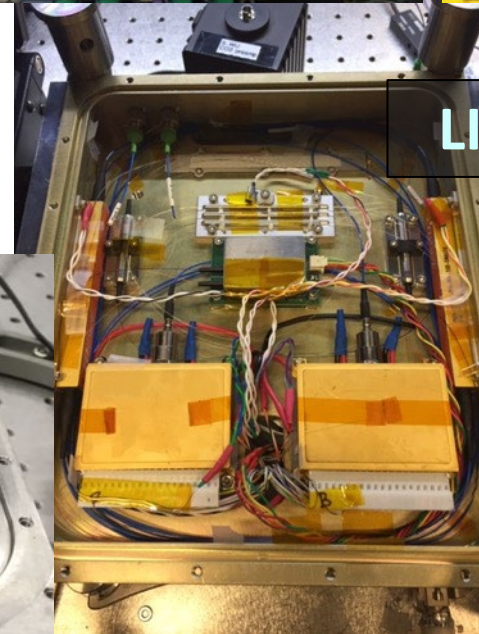
LCRD modem



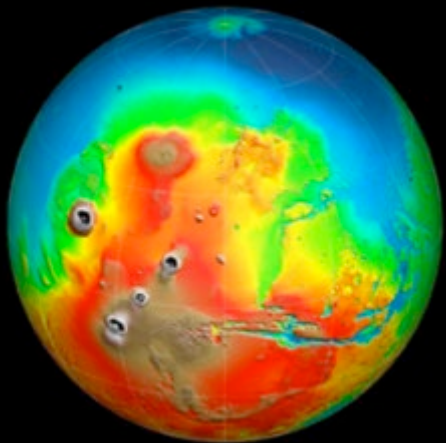
Fiber Optic Amplifier Transmitter



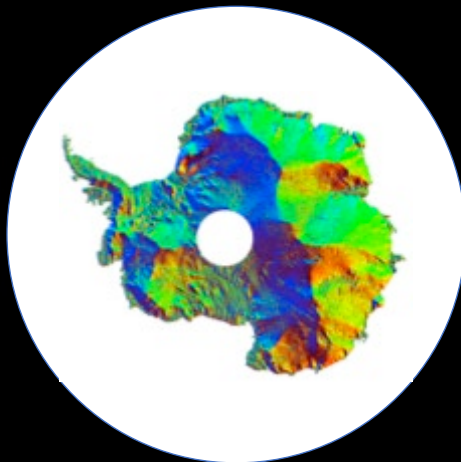
LISA



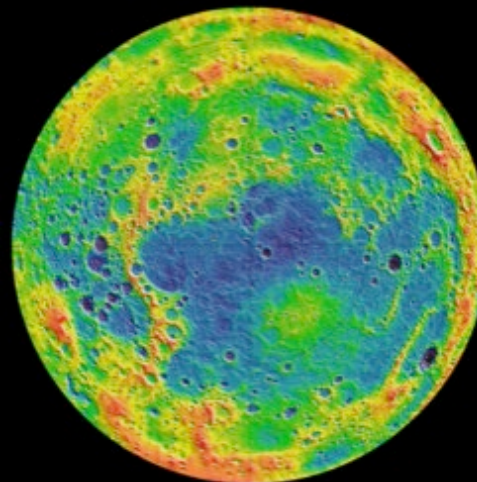
- **Mars Orbiter Laser Altimeter (MOLA)**
- **Geoscience Laser Altimeter System (GLAS)**
- **Mercury Laser Altimeter (MLA)**
- ***Lunar Orbiter Laser Altimeter (LOLA) – still active***
- ***Advanced Topographic Laser Altimeter System (ATLAS)- active***



Mars



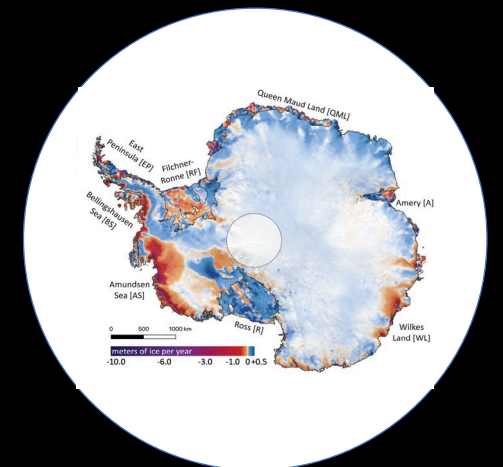
**Earth (Antarctic)
GLAS**



Mercury

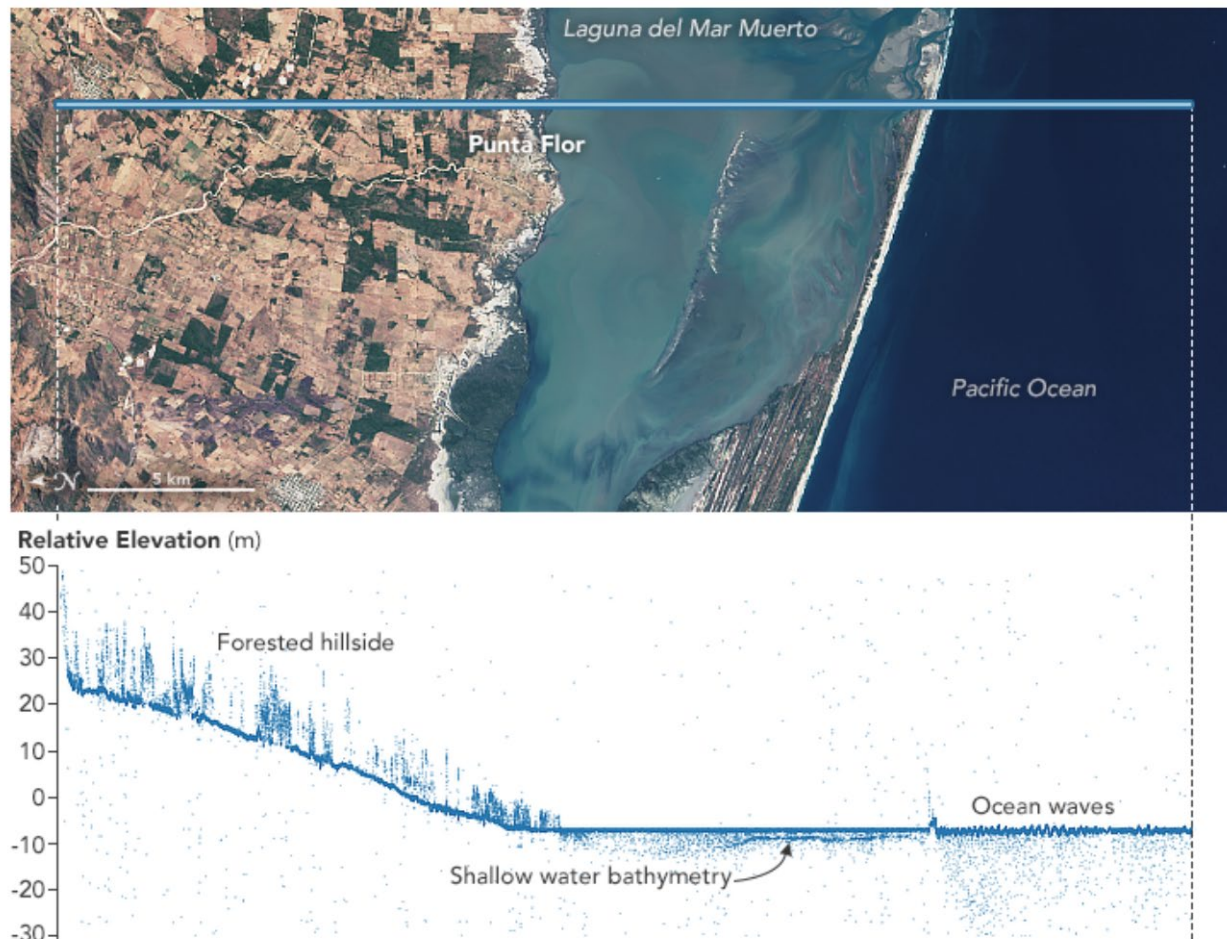


Moon

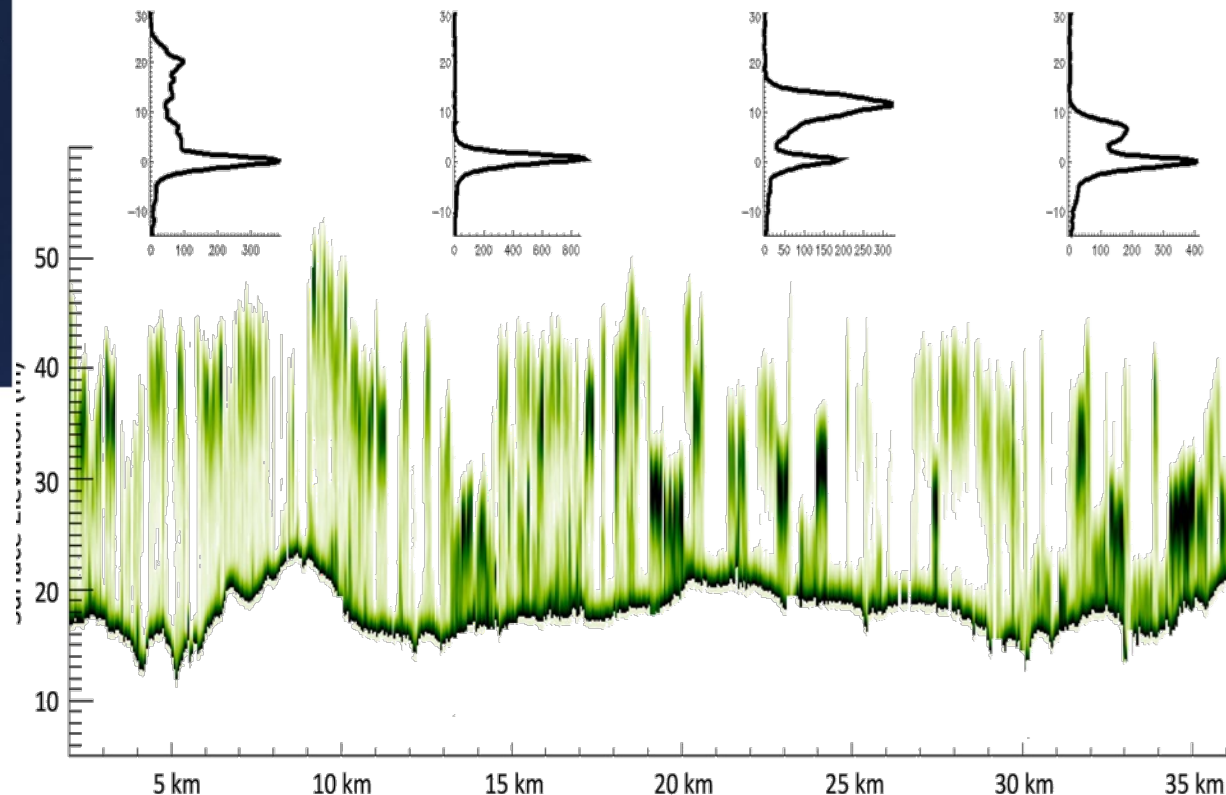


**Earth (Antarctic)
ATLAS**

ICESat-2 Sees the Trees in Mexico



GEDI - Canopy structure taken over South Carolina

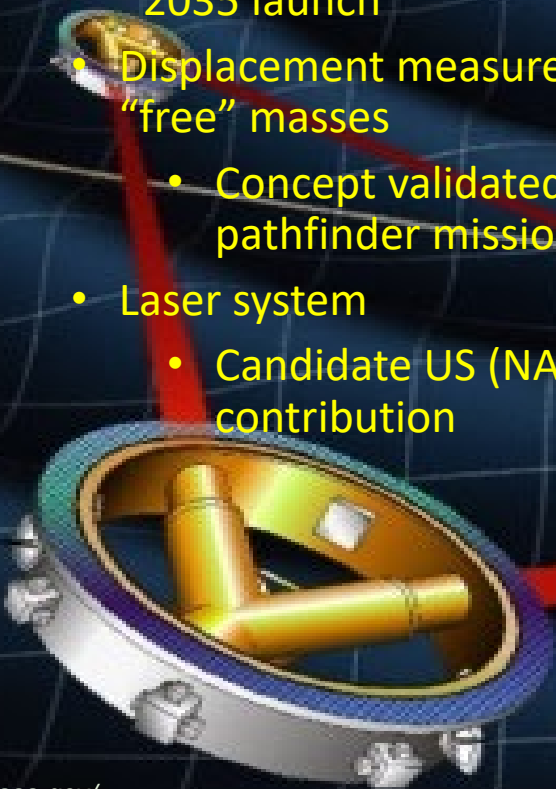


Laser Interferometer Space Antenna (LISA)

- Size of strain h
 - $h \sim 10^{-21}$ for typical GW source
 - $L \sim 2.5 \times 10^6 \text{ km}$ (LISA): $L \cdot h \sim 1 \text{ pm}$
- LISA (Laser Interferometer Space Antenna)
 - ESA (European Space Agency)-led mission, ~2035 launch
 - Displacement measurement between "free" masses
 - Concept validated by the LISA pathfinder mission
 - Laser system
 - Candidate US (NASA) component contribution

High level LISA laser requirements

- Wavelength & power
 - Wavelength: 1064.49nm, >2W on optical bench at EoL,
- Size & mass
 - 200 x 200 x 200mm (incl. electronics), 10kg per laser head (LH)
- Lifetime
 - >16 years (including ground testing, cruise, normal and extended science ops)
- Noise requirements
 - Frequency, intensity, RF phase noise
- Other requirements
 - Dissipated power <50W
 - OP temperature $20 \pm 10^\circ \text{C}$
 - NOP temperature -20°C to $+50^\circ \text{C}$
 - Few mW pick-off for Laser Pre-stabilization System (LPS)
 - Linear polarization



LISA Laser MO: μ NPRO Overall Dimensions (excluding pins and fiber):
 66 x 54 x 14.3 mm (Numata et. al.
<https://doi.org/10.1117/12.2508181>)

<https://lisa.nasa.gov/>



Lasers for *in-Situ* Planetary Lander Instruments

(Mass Spectrometers)



- UV and visible solid-state lasers to explore the surface chemistry of planetary bodies across the Solar System.
- The lasers serve as ionization and excitation sources for mass and Raman spectrometer instruments.
- The laser architecture is based on diode-pumped solid-state laser oscillator and amplifier (when needed) with various stages of non-linear frequency conversion to achieve the required output wavelength for the science instrument.
- Laser enclosures are pressurized with >1 atm of clean dry air to minimize the risk of contamination induced damage associated with UV lasers operating in vacuum.

DraMS



Titan

CORALS



Europa

CRATER



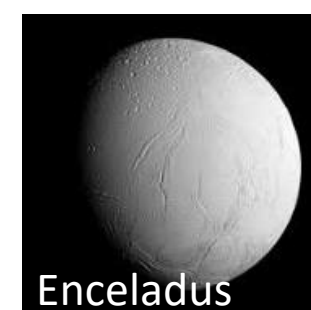
Moon

iSEE



Mars

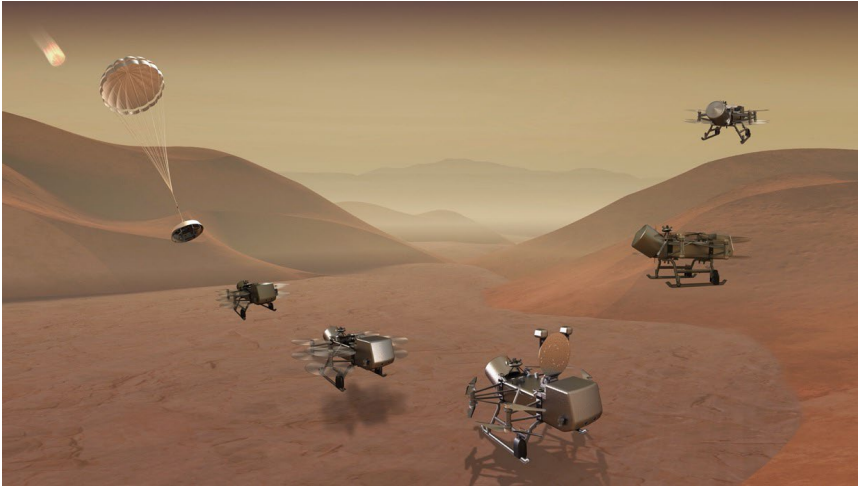
RAMS



Enceladus

Common Science Themes

- Search for extraterrestrial life and potentially habitable environments beyond Earth.
- Further our understanding of the timing and formation of the Solar System.
- Identify potentially viable economic resources such as water and/or valuable metal assets.

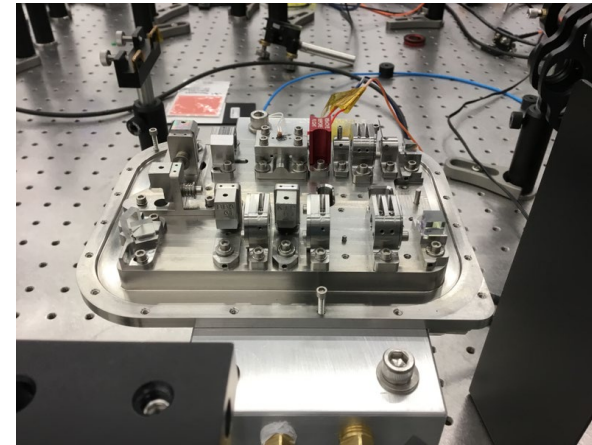


- Dragonfly Mass Spectrometer (DraMS)
- Instrument PI: Melissa Trainer/GSFC
- Launch 2027

The Dragonfly mission will carry a mass spectrometer, DraMS, to characterize the chemical composition of the Titan surface and atmosphere. DraMS will analyze samples in three different modes: Gas Chromatography Mass Spectrometry (GCMS), Laser Desorption Mass Spectrometry (LDMS), and Atmospheric enrichment mass spectrometry (ATM).

The Throttled Hydrocarbon Analysis by Nanosecond Optical Source (THANOS) Laser shown. This includes the diode enclosure, laser optics box, and BSU. It is required to do the following to generate ions for large molecule study on sampled collected on Titan by:

1. Generating 266 nm light in ≤ 2 ns pulses
2. Generating 0.013 to 0.35 J/cm² @ 100 Hz
3. Generating up to 50 shot bursts
4. Provide tunable energy for each laser pulse
5. Survive transit to Titan and produce 2×10^6 shots (includes margin)



THANOS laser ETU unit

Coyle et. al. <https://doi.org/10.1117/12.2644728>

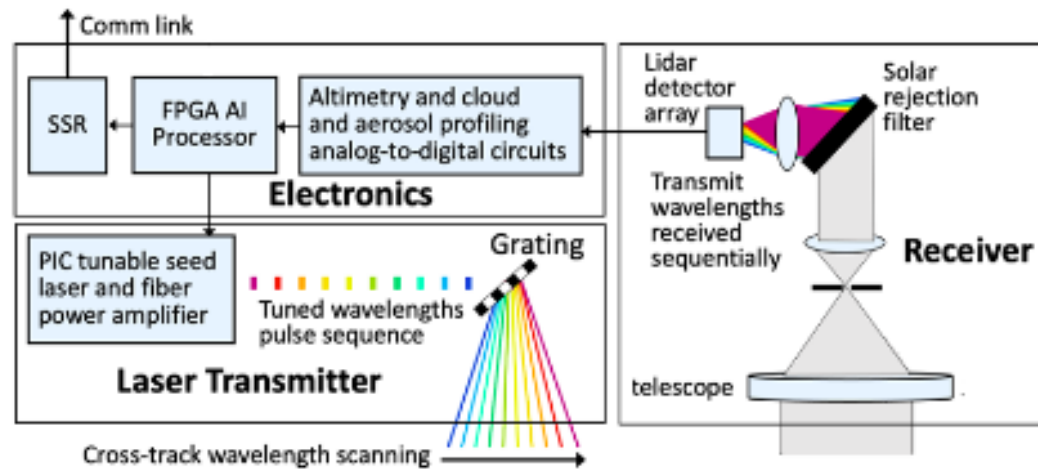
1. Satellite servicing: OSAM-1 – Kodiak laser
(<https://nexis.gsfc.nasa.gov/osam-1.html>)
2. Dragonfly Ocellus Laser Altimeter
3. Safe Landing for Space Exploration - Hazard Detection Lidar (HDL)
4. Adaptive Wavelength Scanning Lidar (AWSL)



The SPLICE HDL system mounted to a pickup to test how it maps the surrounding areas. Source: NASA



Artist's concept of OSAM-1.
Credit: NASA

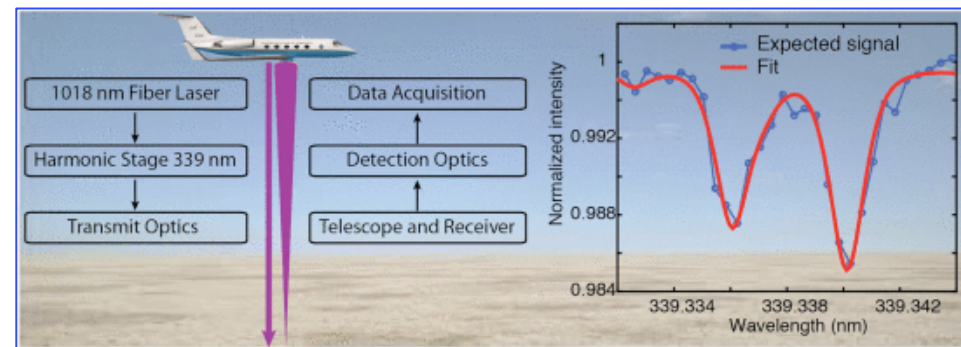


AWSL lidar system block diagram with three major blocks: laser transmitter, receiver, and electronics
(Yang et. al. doi: 10.1109/IGARSS46834.2022.9884418)

KODIAK SYSTEM LASER REQUIREMENTS

Requirements	Values
Operational Time (testing + on-orbit)	~ 1000 Hours
Center Wavelength	1553.xx nm \pm 1.0 nm
Spectral Width	\pm 0.5 nm
Wavelength Drift over Temperature	\pm 3.0 nm and <1.0 nm per 10°C
Minimum Repetition Rate	100 kHz
Maximum Repetition Rate	200 kHz
Pulse Width	2.5 ns (TBR) \pm 0.5ns
Peak Pulse Energy @ 100 kHz	3 μ J \pm 10%
Peak Pulse Energy @ 200 kHz	3 μ J \pm 10%
Dynamic Range	10 dB

- B-SoliTARe: Balloon Sodium Lidar to measure Tides in the Antarctic Region (Heliophysics)
- Formaldehyde Integrated Path Differential LIDAR
- Laser-based Remote Sensing of Atmospheric Carbon Dioxide

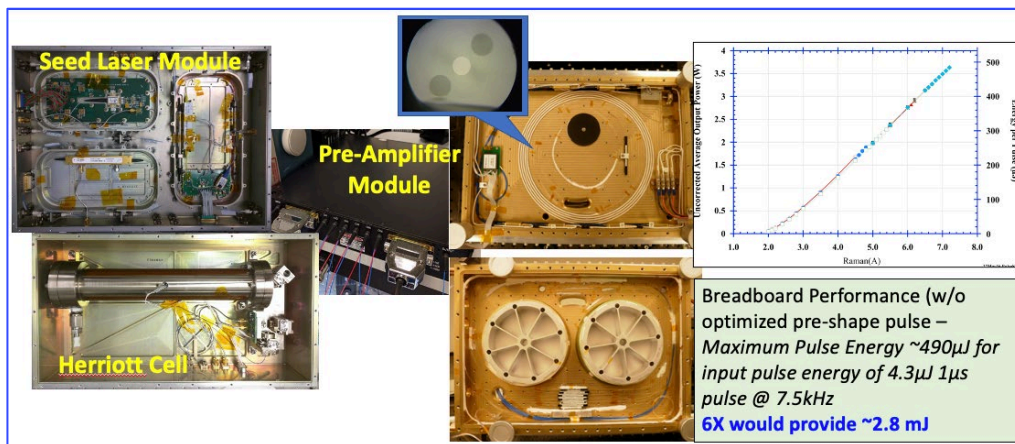


A. W. Yu et al., doi:10.1109/IGARSS39084.2020.9323088.

IPDA lidar uses a tunable laser to measure HCHO with absorption spectroscopy. Instrument includes a tunable laser, a reference cell for HCHO, and a transceiver samples the return signal from the ground.

LASER REQUIREMENTS FOR B-SoliTARE

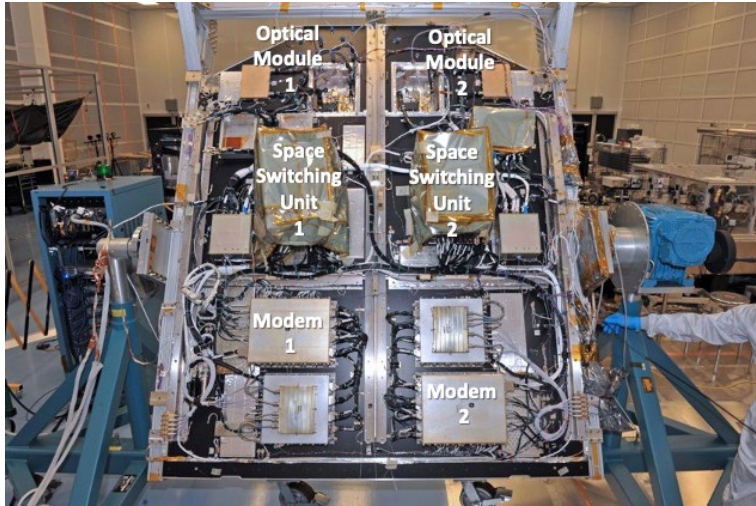
Laser Transmitter Parameters	Value
Wavelengths	589.15900 nm 589.15846 nm 589.15790 nm
Average laser power	1 W
Laser pulse rate	10 kHz
Laser divergence angle	75 μ rad



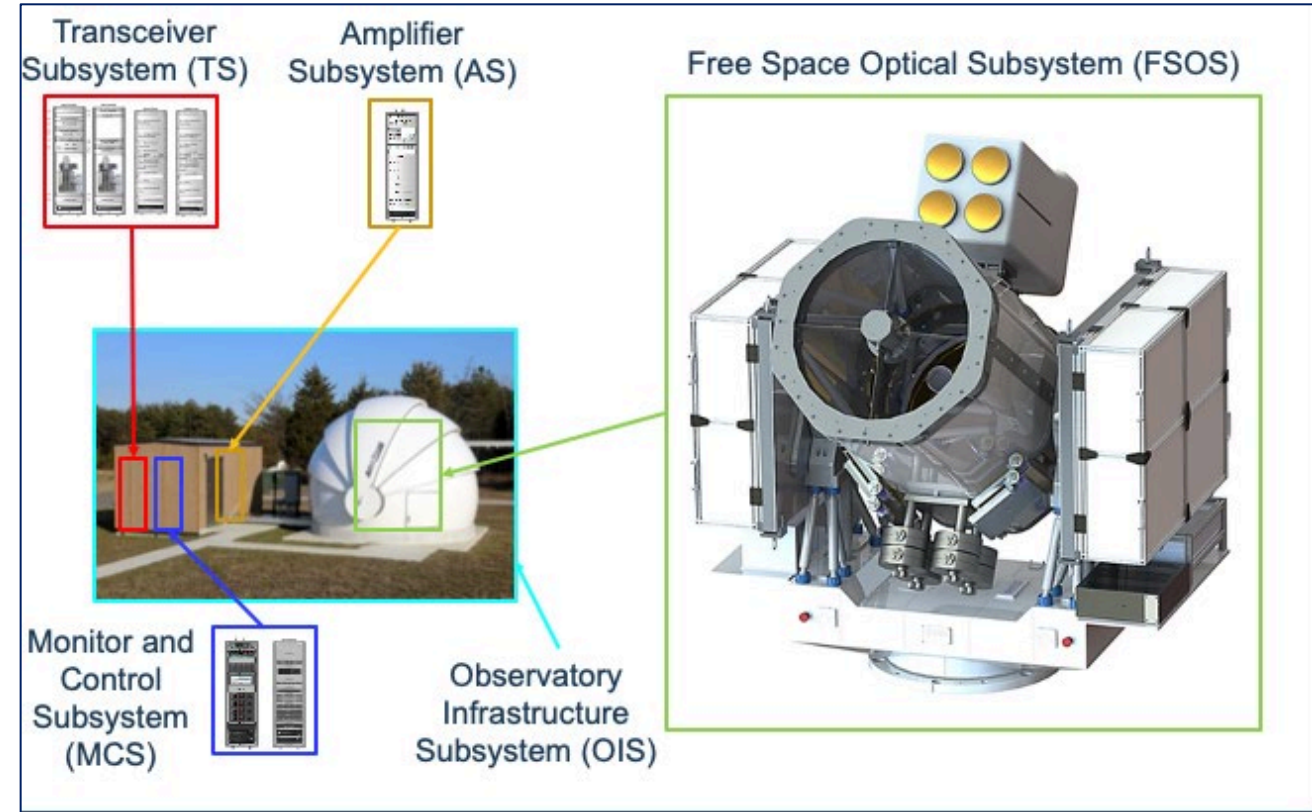
A. W. Yu et al., doi:10.1109/IGARSS39084.2020.9323088.

MOPA Laser at 1572 nm

Laser Communications



Integrated Laser Communication Relay
Demonstration Payload at NASA Goddard Space
Flight Center



The Low Cost Optical Terminal (LCOT) facility at GSFC

Also: High precision optical ranging and range rate experiments planned with LCRD on orbit.



General Laser Requirements



Parameters	Altimetry	Trace Gas Sensing and Spectroscopy	Time-of-Flight Mass Spectrometer	Laser Communications	Precision Ranging
Pulsed Repetition Frequency [PRF]	10's Hz to < 10 kHz for Earth applications to minimize range ambiguity < TBD kHz for planetary depending on atmospheric (or lack of) composition/structure	Few kHz to < 10 kHz for Earth applications to minimize range ambiguity	single shot to 10's kHz	Depending on data format	CW with phase modulation (typ in GHz rate)
Wavelength	1 μm typical	Species dependent. e.g. • 1572 nm for CO_2 ; • 1640 nm or 1651 nm for CH_4 ; • 589 nm for Sodium; • 308 nm for OH	UV, NIR & MIR	User's choice	1 μm
Spectral Width	< 1 nm, for narrow bandpass filter on receiver end	Single frequency - typ. 100's MHz	< 1 nm	100's kHz	Not critical but frequency noise in mHz to kHz band is the driving requirements
Average Power or Pulse Energies	100's μJ	100's μJ to 10's mJ	10's to 100's μJ	few Watts	few Watts
Pulse Width	picosecond to nanosecond	Transform limited pulse width	femtosecond to picosecond	Depending on data format	N/A



Technology Readiness Levels (TRL)



TRL 4

- Component and/or breadboard validation in laboratory environment

TRL 3

- Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2

- Technology concept and/or application formulated

TRL 1

- Basic principles observed and reported

TRL 9

- Actual system “flight proven” through successful mission operations

TRL 8

- Actual system completed and “flight qualified” through test and demonstration (ground or space)

TRL 7

- System prototype demonstration in a space environment

TRL 6 **Necessary Step for Space**

- System/subsystem model or prototype demonstration in a relevant environment (ground or space)

TRL 5

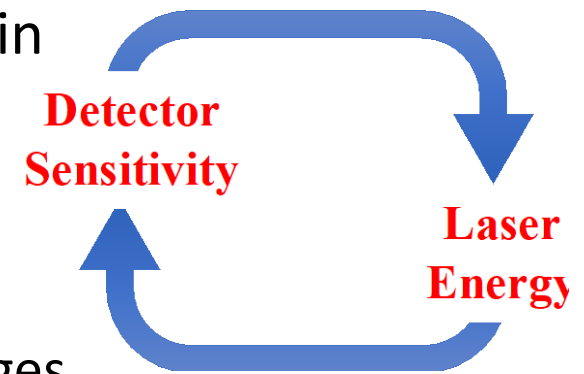
- Component and/or breadboard validation in relevant environment



Preparing for the Future



- Common requirements for all laser-based instruments
 - ❑ Lifetime
 - ❑ Reliability
 - ❑ Efficiency
- For Earth and Planetary Sciences
 - ❑ High rep rate (10's kHz), lower pulse energy (10's - 100's μ J), fS - μ S pulses
 - ❑ High efficiency laser systems (>15% wall plug)
 - ❑ Highly reliable laser systems (multi-Billion shots, or 10+ years in space operation)
 - ❑ High sensitivity detector and detector arrays with low-noise, high speed ROICs
 - linear mode PC in the NIR because of its wavelength advantages





Electro-optics and Photonics Systems for Space Challenges



- Leveraging investments from the telecom and other industries
 - e.g., Telcordia qualified components
- Extensive testing – put them through the paces – TRL4 to TRL6
- Non-Hermetic or environmental sealed components
 - Evaluation of BOM
 - Material selection
 - Contamination induced damages
 - Pressurized enclosure
- Quality Control/Workmanship
- Contamination Control
- Environmental Testing
 - Temperature (Operation and Survival)
 - Vacuum
 - Radiation
 - Shock/Vibration
- Reliability/Lifetime
 - Redundancy Strategies
 - Contamination induced damages
 - Laser induced damages
- Limited Resources
 - Wall Plug Efficiency
 - Operation Margins
- Obsolescence



Summary



- NASA GSFC has been involved in space-borne laser instrument development since mid-90's
- We are actively seeking innovative solutions to meet future science missions' objectives and goals
- Leverage industries and other agencies' funded programs on components and systems development.



Acknowledgement



Represents the work of hundreds of people –

NASA ESTO; NASA PICASSO; HTIDeS; H-FORT; ASTID programs;

GSFC Lasers & Electro-Optics Branch; GSFC IRAD program;

SBIR/STTR programs, Physics of the Cosmos Study (PCOS) Office

and the

Instrument and Science Teams of:

MOLA, ICESat/GLAS, MLA, LOLA, ICESat-2, GEDI, DRAMS, LIST SDT, ASCENDS,

LADEE, LCRD and many more